THE COMBINATION OF A NEW AIR BAG TECHNOLOGY WITH A BELT LOAD LIMITER

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ABSTRACT

This study deals with the development of a restraint system in order to improve occupant protection in frontal impact. In frontal collisions where vehicle intrusion is minor, the main lesions caused to occupants are thoracic, mainly rib fractures resulting from the seat-belt. In collisions where intrusion is substantial, the lower members are particularly vulnerable. In the coming years, we will see developments which include more solidly-built cars, as offset crash test procedures are widely used to evaluate the passive safety of production vehicles. If this trend will continue, restraint forces from the belt will increase and as a consequence more thoracic injuries will occur in frontal collisions.

In order to address this risk, it has become necessary to work on an optimized limitation of the restraining forces, while taking account of the broadest possible population, especially elderly people. A first step in this reduction was taken in 1995 with the introduction of the first-generation Programmed Restraint System (PRS), with a seat-belt force threshold of 6 kN combined with a belt pretensioner. Thirty seven frontal accident cases involving this type of restraint were investigated.

Analysis of these data combined with findings from the University of Heidelberg / NHTSA study, shows that it is necessary to go a step further by reducing the shoulder belt force to 4 kN. As this objective cannot be achieved with a standard restraint system, it was necessary to redesign the airbag and its operating mode that is, a new seat-belt + airbag combination called PRS II.

This paper summarizes the data obtained with the 6 kN load limiter restraint in real-world collisions. A description of the new system is given and its performance in offset crash configurations with respect to a European standard belt + air bag system is discussed.

INTRODUCTION

IMPORTANCE OF FRONTAL COLLISIONS. Detailed analyses of all fatal accident reports in France in 1990 and of the accidentology file of the PSA/Renault Laboratory enabled to determine the distribution of fatalities and seriously injured occupants with respect to collision configurations. The percentages related to frontal impact are respectively 50°/0 and 70%, as shown in Figure 1 ; illustrating the predominant role of this crash configuration on occupant injuries. In order to assess the distribution of lesions in frontal collisions as regards the main body segments, an analysis was conducted on 100 belted front seat occupants taking into consideration serious injuries. Figure 2 presents the distribution of AIS 3+ injuries for the head, the thorax, the abdomen and the lower members. It can be observed that the thoracic risk is highest for the passenger, and secondly, for the driver. For the latter, injuries to the lower member's constitute the most frequent risk. Since 1992, improvements have been noted in Europe in cars as regards the resistance of the passenger compartment, especially the reduction in intrusion. In addition the majority of cars are today equipped with belt pretensioners. The combination of these improvements would suggest a certain benefit in reducing the severity of injuries to the occupant. To assess this hypothesis two accident files, including belted drivers involved in frontal collisions, were selected. The first file (A) comprises 2000 vehicles manufactured before 1991 and with no belt pretensioners in the restraint system. The second file (B)

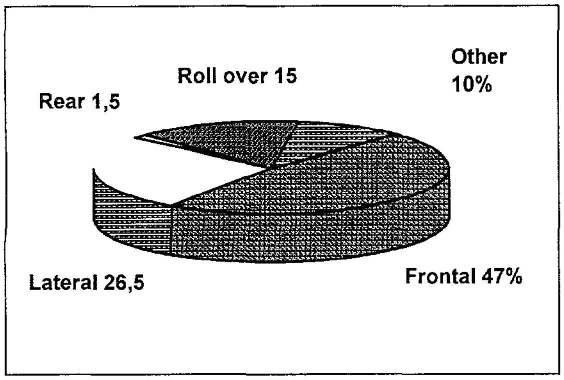


Figure 1a : Distribution of fatalities per collision type. LAB PSA/Renault accident database.

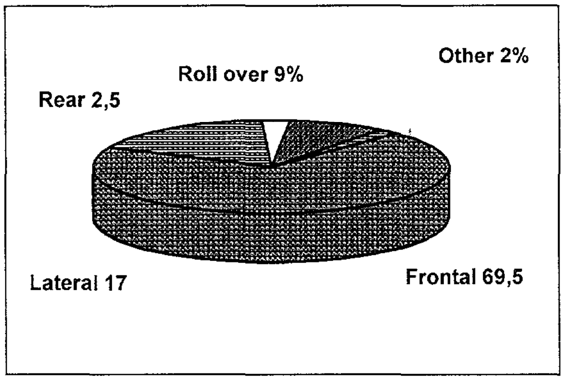


Figure 1b : Distribution of severely injured occupants per collision type. LAB PSA/Renault accident database.

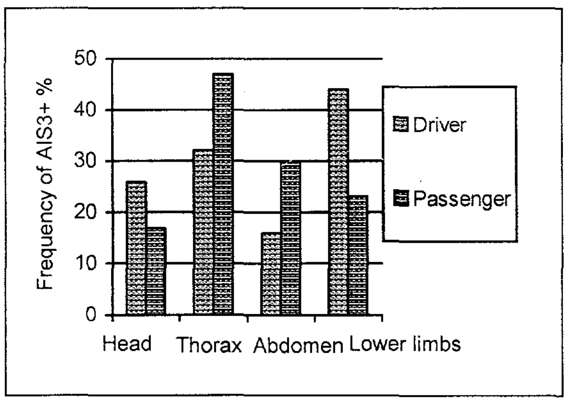


Figure 2 : Distribution of severe injuries per body regions for 100 seriously injured occupants (MAIS 3+) in frontal collisions. Driver and front seat passengers (belted).

includes 160 vehicles, manufactured since 1992, all equipped with belt pretensioners and structural reinforcements. The two files were compared taking into account the frequency of moderate to serious injuries, AIS 2+ , corresponding to the main body segments, as shown in Figure 3.

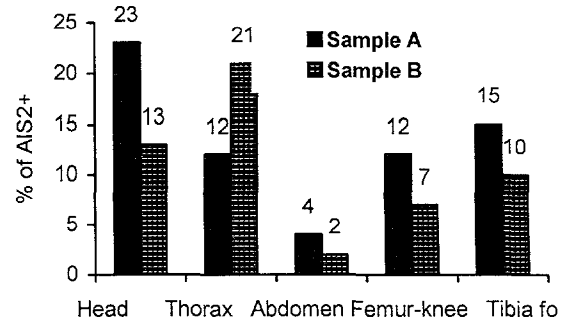


Figure 3 : Risk of AIS 2+ injuries in frontal collisions involving belted drivers. Comparison of 2 accident samples with cars manufactured before 1991 (A) and cars manufactured since 1992 (B).

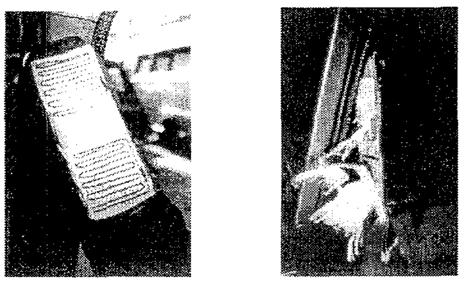
When comparing files A and B, a tendency in the reduction of injury frequency is observed for the head, the abdomen, the lower limbs. For the thoracic segment an opposite trend appears with an increase of risk. As this tendency to reduce intrusion will continue and, as airbags will become more widespread in Europe, one may expect gains as regards the risk of injuries to the head and lower members, and abdominal risks will be maintained. For the thorax, there will be increased risk since rigidifying the structure will result in a direct increase in restraining forces on the occupant. A study presented by Bendjellal, 1997 (1), showed accident cases in frontal collisions with cars manufactured after 1992, where front seat occupants, restrained with a combination of a belt pretensioner and an air bag, sustained severe thoracic lesions.

The study presented in this paper was initiated in order to address this rising risk of chest injuries.

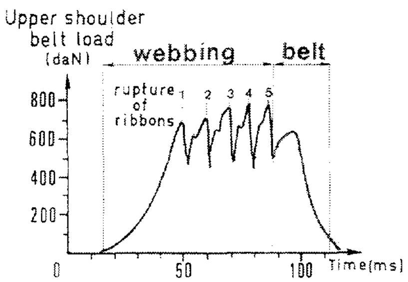
THORACIC RISK LINKED TO SEAT-BELT

BELT INDUCED INJURIES AND OCCUPANT AGE - The 3-point seat-belt was designed to protect the occupant as regards contact with the passenger compartment and to avoid ejection from the vehicle. In order to provide this protection, the seat-belt exerts substantial and localized forces on the thoracic cavity. These forces, which may reach 10 kN, generate broken ribs which may or may not be combined with internal lesions of the thorax. The first relationship between seat-belt tension and the associated thoracic risk level was established by J.Y. Forêt Bruno in 1978 (2) based on an analysis of 90 accident cases. The vehicles in question, sold in France in the

1970's, were equipped with 3-point static seat-belts in the front seats with a load limiter located in the belt webbing between the occupant's shoulder and the upper anchorage point. The load limitation was obtained by tearing of the stitching which was used to sew loops in the webbing. In case of impact the stitching tore, thus allowing more webbing from the loop: as a consequence the torso can move relative to the vehicle at a controlled load level. A view of such a load limiter before and after impact is shown in Figure 4a and its force-time response in dynamic test is illustrated in Figure 4b.



a) Load limiter before and after impact



FORCE LIMITER type B

b) Response of load limiter in dynamic test

Figure 4 : A load limiter installed in cars sold in France between 1970 and 1977

In 1989, other cases were added to this investigation, bringing the total of this database up to 290 accidents (3). The key point of this unique database is the possibility of showing a relationship between the seat-belt tension exerted on the occupant, his age and the type of resulting lesions: this relationship, reproduced from Forêt Bruno study (3), is given in Figure 5. This data clearly shows that thoracic risk among occupants restrained by seat-belts increases with age and that a shoulder belt force of 8 to 9 kN may induce a high risk for the chest.

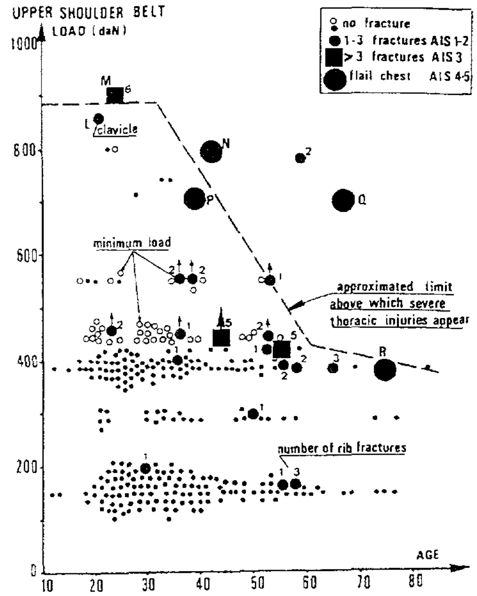


Figure 5: Relationship between shoulder belt tension, age of occupant and injury severity to the chest. Reproduced from (3).

LIMITATION OF THORACIC RISK LINKED TO SEAT-BELT

The data discussed in the previous sections and these accident cases show the necessity of reducing seat-belt tension forces in frontal crashes. An initial stage, consisting of limiting this force to 6 kN, was carried out in 1995 on Renault vehicles with the introduction of the PRS system (Programmed Restraint System). This system is comprised of a pretensioner pyrotechnic buckle, a retractor webbing clamp and a steel part, fastened between the retractor and the seat- belt anchoring point as shown in Figure 6. This part, designed to deform at a given level of force, acts like a force limiter. The system's operating method includes 3 phases: at the beginning of the impact (15 milliseconds),the buckle pretensioner triggers in order to take up the seat-belt/occupant slack. The occupant's coupling is increased in this phase with the action of the strap blocking mechanism in the retractor (17 ms). This combination enables one to substantially reduce the occupant's initial displacement. In Phase 2, restraining forces are gradually applied. When the belt tension level reaches 6 kN (70 milliseconds) the force limiter comes into play, authorizing controlled displacement of the retractor in the B-pillar, upwards. Movement of the retractor will enable a displacement of the torso under controlled load, thus allowing the rib cage to be relieved of seat-belt stresses. Complete operation of this device is shown in Figure 7.

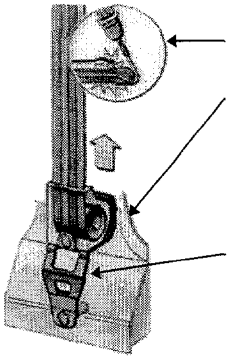


Figure 6: The Programmed Restraint System installed in Renault cars since 1995 (6 kN shoulder belt load limiter)

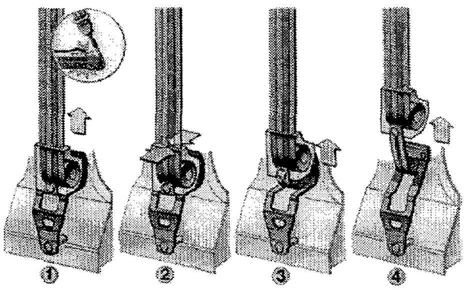
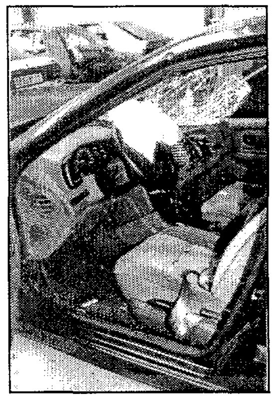


Figure 7. The PRS operating mode - Phase 1 Initial part of the crash and belt pretension activation, Phase 2 Action of the webbing clamp, Phase 3 Load limiter activation, Phase 4 End of impact

Behaviour of the Programmed Restraint System in Real - World Accidents - To date, 80 accident cases related to frontal collisions with cars equipped with this device have been investigated since 1995. Thirty seven cases are discussed in this paper. The main parameters of this sample are summarized in Figure A1 in the appendix. Age distribution of occupants ranges from 17 years to 72 years , with 11 cases (30%) with age < 25 years, 7 cases (19%) with age ranging from 26 to 35 years, 3 cases (8%) between 36 and 45 years, 8 cases (21.5%) between 46 and 55 years, and 8 cases (21.5%) with age > 56 years. The severity of the collisions, expressed in terms of EES, ranges from 35 km/h to 75 km/h. Nearly half of this sample (48.6%) corresponds to a severity which is superior to EES of 55 km/h.

Regarding the injury severity for the thorax, only 2 cases(5.4%) are related to an AIS level of 3. In the first case the driver a 72 old male sustained 3 right rib fractures and lung contusion. The car was involved in an offset collision to the left, with an overlap of 85% and with an EES of 50- 55 km/h. Except fractures to the left metatarsi, no other injuries were found. In the second case two front seat occupant were involved; a 58 years old male in the driver position and a 60 years old female in the passenger position. The driver sustained a fracture to the sternum (AIS 2) and. the passenger had 4 left rib fractures (AIS 3). In both .accident the shoulder belt load. estimated from the PRS deployment, was 6 kN. The other thoracic AIS levels observed for the rest of the sample are AIS 2 with 7 cases (19%) , AIS 1 with 13 cases (35%) and AIS 0 with 15 cases (40%).

Regarding the overlap distribution among these accident cases , half of the sample corresponds to offset configuration with an overlap below 74%° and the other half is close to a full barrier test. An illustration of one accident, case No . 12041, is given in Figure 8 with photographs of the car deformation and the PRS deployment.



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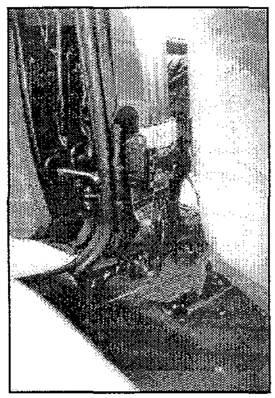

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Figure 8 : Illustration of car deformation in a frontal collision Case No 12041 (9a) and the PRS actual deployment (9b).

Belt limitation threshold - The accident cases presented in the previous section, are encouraging, but they show that a threshold of 6 kN for belt load limitation is not sufficient to prevent a risk of serious injury to the thorax as 2 cases with occupants having sustained an AIS 3 level were found. This observation is consistent with the data from Forêt Bruno (3) published in 1989. It is therefore necessary to go a step further in the reduction of shoulder belt load. As this reduction will result in an increase in excursions of the head and thorax it is therefore essential that with this kind of seat belt it is necessary to combine the pretensioner and quite obviously the airbag. The combination of an airbag and a 3 point belt restraint is discussed in various publications among them are the paper from Kompass in 1994 (4), the study of Kallieris et al in 1995 (5) and Mertz et al investigation in 1995 (6). According to the data discussed in Kallieris paper (5) and the mathematical simulation investigated by NHTSA (5) for a variety of crash conditions (frontal and rollover) crash severities and occupant sizes (5, 50 and 95 percentiles) a threshold of 4 kN for the shoulder belt load limitation appears to be suitable for reducing the risk for thoracic injury without negative consequences on other injury measurements. Therefore a 4 kN load limitation threshold is chosen for the belt system. Whilst working in the same stopping distance for the thorax, i.e. a distance from thorax to steering wheel of 300 to 350 mm, it is necessary for the airbag to play an important role by taking part of the thoracic restraint. The question is : which type of air bag has to be chosen for this occupant protection approach ?

Air bag accident data in the USA and in France - When the FMVSS 208 was introduced in the USA in the beginning of the 1980's, according to investigations carried out by NHTSA, most people did not use seat belts. The percentage of people wearing seat belts at that time was on the order of 15%; this suggested the necessity of protecting the majority of unbelted occupants, by means of a restraint system independent of the seat belt The physics of a vehicle, impacting a rigid barrier at 50 km/h and with 50th percentile dummies not restrained by a seat belt, imposed de facto paddings or knee plates for the protection of the femurs and knees and the airbag for protection of the upper part of the body. The performance of such a restraint system combined with the seat belt is quite positive with more than 1500 lives saved (7) during the 1990 1996 period. However cases of fatal accidents have been noted involving either adults not restrained by seat belts or else children in rearfacing seats or even children without any restraint system whatsoever. This problem stems mainly from the energy parameters of the airbag dimensioned in order to absorb energy on the order of 3000 J. In comparison, a Eurobag or « facebag ». designed to protect the head of a 50° percentile restrained by seat belts has an energy potential of 200 J. If one wants to design a seat belt airbag restraint system which takes account of OOP situations, it is therefore necessary to explore other possibilities.

Current situation in France - Out of the total number of automobiles in France - some 25 million - only 2 to 3% of vehicles are equipped with driver airbags. We lack data on airbag efficiency in Europe since the target survey files remain statistically low in comparison with the USA, only 100 cases have been studied in France by the Laboratoire d'Accidentiologie et de Biomécanique Peugeot Renault; 75 cases involved frontal collisions with belted drivers.

In Figure 9 a risk comparison for the head, with and without airbags, is given. For the 25 to 45 km/h speed range, one notes moderate lesions (11%) for cases with no air bag as opposed to 0% for cases with air bag. For the 46 to 65 km/h speed range, the frequency of AIS > 2 is 40% without air bag and only 14°/o with air bag. No facial fractures were observed with air bag, whereas half of the sample without air bag represents facial fractures. The tendency of air bag to improve head protection is confirmed.

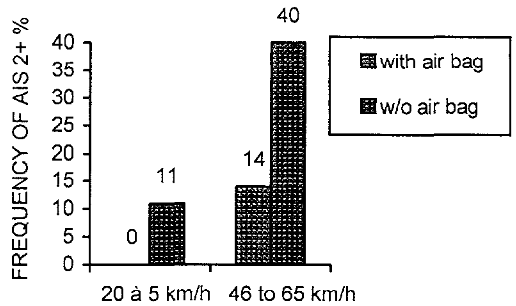

Figure 9: Accident survey with frontal collisions involving occupants with 3 points belt + Air bag restraint system. Frequency of AIS 2+ injuries to the head. All cases with Eurobag type of air bag.

SPECIFICATIONS FOR AN OPTIMIZED SEAT-BELT + AIR BAG RESTRAINT SYSTEM - The basic principle is that occupant restraint energy must be managed, whilst complying with human tolerance limits. In this context, the thoracic cavity is more tolerant to distributed pressure (air bag) than to a very localized pressure (belt). With the same stopping distance for the occupant in the vehicle, it is possible for the airbag to take a part of the seat-belt forces.

Once the basic elements of the seat-belt, that is, pyrotechnic pretensioner and force-limitation, have been determined, it is now necessary to define the airbag characteristics. The corresponding specification is based on 2 separate parts: to contribute actively to restraining the occupant, and to control the aggressiveness of the deployment of the airbag. This results in the 3 following main functions:

1. The airbag must inflate very early on in the impact and "wait for" the occupant's contact; this is the anticipation function, analogous to the effect of a pretensioner on the PRS seat-belt.
2. Having a law of force which is as constant as possible. This is equivalent to controlling

the pressure in the airbag and the force exerted on the occupant. This is similar to the action of the force-limiter in the PRS seat-belt.

3. These two functions result in an increase in the generator power in relation to the Eurobag. In order to control the bag aggressiveness in OOP situations, it is necessary to compensate this through a more elaborate airbag-folding strategy, in order to reduce the punch out transmitted to the occupant. This objective results in a deployment mode distributed in 3 directions: first downwards and sideways and then toward the occupant.

Based on these elements, a new airbag has been developed in the frame of the new system called the PRS II.

DEVELOPMENT OF THE PRS-II DESCRIPTION AND VALIDATION

The system comprises 3 main components. These are the pretensioner, the belt load limiter and the air bag.

The pretensioner - This is a device which enables the seat-belt strap to be drawn taut very quickly at the initial moment of impact. For the PRS-II system, and given the experience acquired on Renault vehicles since 1992, a pyrotechnic buckle pretensioner has again been selected, especially for its efficiency with respect to submarining. In 4 milliseconds, it enables to take up the seat-belt slack and secure the occupant to the seat.

The seat-belt force-limiter - The force limitation function is located at the core of the retractor with a torsion bar whose plastic deformation comes into play as soon as the seat-belt force at the shoulder reaches 4 kN. For this function an another option is to use the deformable steel plate, as in the PRS-1 generation, providing a sufficient space in the B-pillar packaging.

The airbag - The airbag is a 60 liters bag with a pressure limitation function and a folding which allows a deployment from top to bottom and to the sides. As opposite to Eurobag, this bag is defined to protect the head and the thorax. There are different ways to control the pressure of the air bag; the system described here refers to a set of vents in a row, contained in a meltable seam. After an impact, the air bag deploys to its full volume, while the vent is still closed. Ones At a given pressure of the gas inside the bag, the seam tears and the vents open successively. The restraint force acting on the occupant from the air bag is thus controlled.

Development of the PRS II - After a computer simulation phase, the opening pressure of the airbag vents has been validated during tests using a free fall pendulum system. At the same time, the seat-belt force limiter was developed. Then, sled tests were conducted in order to fine-tune the system's characteristics. The validation program also included static tests in OOP , according to ISO recommendations (8), and crash tests with vehicles.

Figure 10 provides a description of PRS-II components. The operating phases of the system, as obtained in a 50% offset rigid barrier test, are illustrated in the same figure where the 4 upper sequences indicate the air bag work and the 4 lower sequences relate to the belt actions. Sequence 1 in Figure 10 represents the firing of the belt pretensioner at 12 ms followed by the start of air bag deployment at 15 ms. Note that once the air bag deployment is achieved (sequence 2) , the vents are still closed; the air bag is waiting for the occupant. When the thorax contacts the air bag, in sequence 3, the seam covering the vents starts to tear, thus liberating the first vent. The bag pressure is now under control; in sequence 4 the belt load limiter function starts to work in conjunction with the opening of the remaining vents in the air bag: with this last sequence the thoracic restraint loads are controlled thorough the impact duration.

COMPARISON OF PRS II WITH A CONVENTIONAL RESTRAINT SYSTEM - Various mathematical simulations and sled tests were conducted in order to assess the PRS-I I performances in frontal collisions. In addition two crash tests with the same vehicle model (mass of the vehicle 1200 kg) were performed; the test configuration corresponds

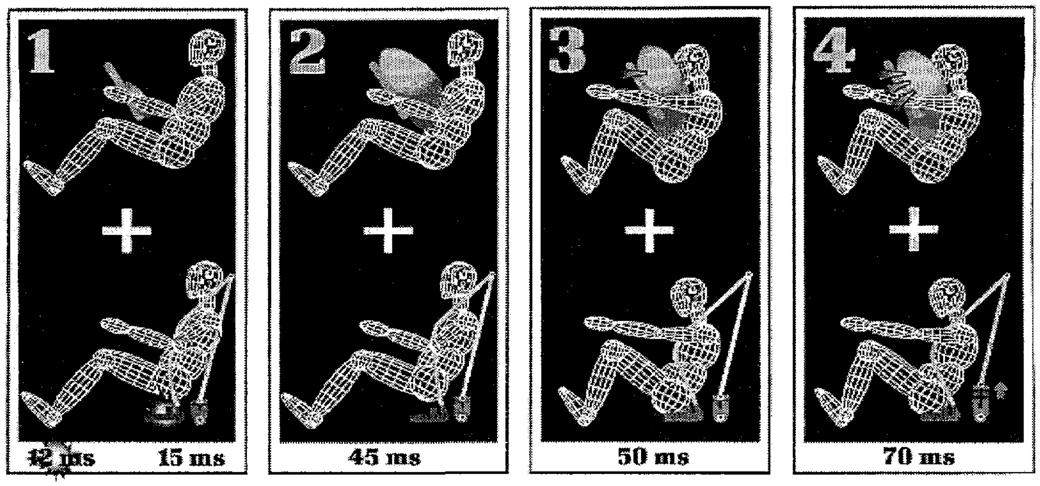

Figure 10: PRS II principle - 1- Pretensioner action and air bag deployment ; 2- air bag full deployment ; 3- Opening of the first vent of the bag ; 4- Combination of belt load limiter action and air bag pressure control (opening of the other air bag vents).

to a 50 % offset rigid barrier test at 56 km/h. One of the vehicle was equipped with a conventional belt + air bag system; the belt included a pyrotechnic buckle pretensioner and the air bag was of Eurobag type(volume of 45 liters). The other vehicle had the PRS-II system. In the front seats of both vehicles instrumented Hybrid III 50° dummies were installed. The results from both tests are illustrated in Table 1 and time-histories for the head acceleration, the chest acceleration and the shoulder belt load are provided in Figure A2 in the appendix. With the PRS-II the head HIC and 3ms acceleration are reduced, respectively 75% and 55% : the neck shearing force is also reduced respectively 60% for -Fx and 57% for +Fx. The neck extension moment is increased with the PRS II with a maximum of 35 Nm as opposed to 11 Nm with the conventional system. The shoulder belt load reduction with the PRS-II is significant -55%, as a direct result of the combined work of the belt and the airbag. The thoracic acceleration is also reduced but the amount of reduction (24%) is smaller than those observed with the other criteria. This last result shows that 1) the occupant stopping distance is the same for the 2 systems we are comparing and 2) the energy distribution on the thorax is spread differently with the PRS-II. Chest injury parameters, such as the chest deflection and the VC, cannot be compared as the data corresponding to the conventional system (with the same vehicle) are not available. The maximum chest deflection and VC with the PRS II are 25 mm and 0.09 m/s. Compared to the conventional system the PRS II allowed an increased x-displacement of the chest (+60 mm).

Results of PRS-II validation in vehicles tests - Vehicles from the same model whose front seats were equipped with PRS 11 were tested according to 3 impact configurations . 1. Rigid obstacle, 15° barrier, 50°70 offset and a speed of 56 km/h according to AMS procedure (9), 2. Deformable barrier at 0°, 40°70 offset and a speed of 56 km/h. This configuration reproduces the future European regulatory test, ECE 94 (10), 3. Full rigid barrier, wall at 0°, and a speed of 56 km/h. This test is the representation of the New Car Assessment Program (NCAP) as used by NHTSA in the USA. The interest of such a test matrix is to combine demanding conditions for the restraint system - the case of the US NCAP test - and for the structure of the vehicle with the other two offset crashes. The first offset test condition allows to assess both the structure of the vehicle and the restraint system. The test according to the procedure defined by the EEVC (ECE 94) is a special case, since this configuration enables to simulate a car to car collision and also to judge the quality of the triggering system for the belt restraint and the airbag restraint, in particular as the first part of the crash is soft compared to the two other test configurations.

The results of these tests are documented in Table 2, which includes the resulting accelerations of the head and thorax, the Head Injury Criterion (HIC 36 ms) the upper neck shear force, the upper neck extension moment, and the shoulder belt tension, the chest acceleration, the chest deflection and VC. All the maximum values refer to measurements obtained from Hybrid III 50° percentile dummy, for both the driver and passenger.

Table 1: 50% offset rigid barrier test at 56 km/h. Comparison of PRS II responses with those of a conventional belt + air bag system - Same vehicle used in both tests, driver data.

	Measurements & injury criteria with a Hybrid III 50° percentile dummy	50% Offset rigid barrier test, 56 km/h with a conventional restraint system	50% Offset rigid barrier test, 56 km/h with the PRS II
Restraint system	Buckle pretensioner activation time (ms)	18	16
	Belt pretension (mm)	49	49
	Initiation of belt load limitation (ms)	None	70
	Duration of belt load limitation (ms)	None	40
	Air bag type	Eurobag 45 liters	PRS II 60 liters
	Time of actiation of air bag pressure limitation (ms)	None	72
Body segments Head	HIC 36 ms	763	186
	3 ms acceleration (G)	74	33
Neck	Shear Force -Fx (kN)	0.5	0.2
	Shear Force +Fx (kN)	0.7	0.3
	Extension moment (Nm)	11	35
Thorax	Shoulder Belt Load (kN)	9.7	4.3
	3 ms acceleration (G)	53	40
	Chest deflection (mm)	na	25
	VC (m/s)	na	0.09
	Thoracic X-displacement measured at shoulder level (mm)	290	350

Table 2 : Summary of crash test results with a production vehicle (mass 1200 kg) equipped with PRS II in offset and full barrier tests. Driver and passenger injury criteria and measurements.

Body segments	Measurements & injury criteria with a Hybrid III 50° percentile dummy	50% Offset rigid barrier test, 56 km/h		100% rigid barrier test,56 kmh US NCAP		40% Offset deformable barrier test, 56 km/h EEVC procedure	
		Driver	Passenger	Driver	Passenger	Driver	Passenger
Head	HIC 36 ms	186	257	347	519	74	111
Neck	3 ms acceleration (G)	33	37	45	53	24	28
	Shear Force -Fx (kN)	0.2	0.03	0.5	1.2	0.009	0.02
	Shear Force +Fx (kN)	0.3	0.6	0.4	0.2	0.5	0.3
	Extension moment (Nm)	35	28	29	na	11	12
Thorax	Shoulder Belt Load (kN)	4.3	4.5	4.6	4.8	3.9	4.1
	3 ms acceleration (G)	40	36	42	45	23	24
	Chest deflection (mm)	25	27	40	40	23	15
	VC (m/s)	0.09	0.22	0.64	0.64	0.01	0.03

The PRS-II system behaved well in all 3 configurations, both belt load limiter and air bag pressure limiter worked. The shoulder belt tension was between 3.9 kN and 4.8 kN. The lowest value was recorded for this parameter was obtained in the EEVC test (for the driver) and the highest value in the US NCAP test (for the passenger). This difference is due to the friction in the D-ring. As this friction is directly related to the dummy forward displacement, its effect on the shoulder peak load is more pronounced for the passenger. Chest accelerations were all below 46 G; this result indicates no chest to steering wheel contact. Neither head to steering wheel contact was observed as illustrated by the low values recorded with the HIC (between 74 and 519) and with the head 3ms acceleration - between 24 G and 53 G. Chest deflections ranges from 15 mm to 40 mm; the lowest value was obtained in the EEVC test for the passenger and the highest in the NCAP test for both the driver and the passenger.

VC values were between 0.03 m/s and 0.64 m/s. Both head and chest accelerations and also chest deflections and VC's ensure that the use of belt load limitation, in the test conditions described here, combined with air bag pressure control has no negative effects on injury measures.

Consideration of neck secondary risk in OOP - An evaluation of the new airbag was performed in static deployment tests using the Hybrid III 50° dummy, in order to measure the risk for the neck region. The results indicate that none of the IARV (11) levels was exceeded. Detailed results of these tests, as well as a biomechanical evaluation of this airbag can be found in Trosseille paper (12).

SUMMARY AND CONCLUSION

This study was initiated to address the rising risk of belt induced chest injuries in frontal impact. The starting point was the analysis of 290 frontal accident cases with vehicles that were equipped in France in the 1970's with a belt load limiter in front seats. The load limiter was based on a tear-webbing principle and was located near the upper belt anchorage point. This database shows that older people (≥ 50 years) may sustain severe chest injuries. Based on this experience a program was initiated at Renault with a view to reduce the shoulder belt load. In 1995, a belt restraint system called PRS was introduced; it comprises a combination of a pyrotechnic pretensioner located at the buckle, a clamp retractor and a steel part attached to the retractor and to the belt anchorage point. This steel part designed to deform at a given load, acts as a load limiter. This allowed to control the shoulder belt load at 6 kN level. Accident cases involving this type of restraint were collected and analyzed; in particular the behavior of the belt load limiter was investigated in relation with occupant injuries. The data from 37 cases with belted front seat occupants, are reported in this paper. Crash severities ranged from 35 km/h to 75 km/h. A significant part of this sample, 27% of occupants with age > 50 years, sustained minor to moderate chest injuries. The combination of belt pretension and a 6 kN belt load limitation appears to have benefits in reducing thoracic loads from the belt for this population; the 6 kN level is however not sufficient to cover the whole population. Thus, a further step in reducing the shoulder belt load is necessary. As this reduction will involve increased excursions of the head and the thorax, the belt load limitation has to be combined with an air bag.

The combination of an air bag and a 3-point belt restraint was discussed in various publications among them are the paper from Kompass in 1994 (4), the study of Kallieris et al. in 1995 (5) and Mertz et al. investigation in 1995 (6). According to the data discussed in Kallieris paper (5) and the mathematical simulation investigated by NHTSA (5) for a variety of crash conditions (frontal and rollover), crash severities and occupant sizes (5° , 50° and 95° percentiles) a threshold of 4 kN for the shoulder belt load limitation appears to be suitable for reducing the risk for thoracic injury, without negative consequences on other injury measurements.

From the experience acquired with the PRS a new approach in the occupant restraint system was developed. The PRS-11 combines a pyrotechnic buckle pretensioner with a 4 kN belt load limiter and an air bag specially designed with respect to 2 key factors: a deployment to the sides and from top to bottom in order to reduce the risk in OOP situations and a pressure control which operates when a certain load is applied by the thorax. One the major concern with the belt load limitation was the possibility to increase the injury risk for the head and for the thorax. A comparison of PRS II with a conventional restraint system was performed, for the driver , on the basis of offset frontal collisions involving the same car model. The data with PRS II show substantial reductions for the head and chest acceleration, HIC values and neck shear forces. Neck extension moment is increased with the PRS II but the value , 35 Nm, remains below the 57

Nm suggested IARV (11). Maximum chest deflection and VC obtained with PRS II were 25 mm and 0.09 m/s. These data were not compared to those of conventional system, as the corresponding data were not available for the same car model.

The PRS II was also evaluated in 3 frontal collisions: offset rigid barrier test at 56 km/h, offset deformable barrier test at 56 km/h (EEVC frontal impact test procedure), and in full rigid barrier test at 56 km/h (NHTSA frontal NCAP test). In the test conditions described here, the combination of a 4 kN belt load limitation with the pretensioner and air bag pressure control has no negative effects on injury measures.

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REFERENCES

1- F Bendjellal, G Walfisch, C Steyer, P Ventre, J.Y Forêt-Bruno, X Trosseille, J.P Lassau : « The Programmed Restraint System - A Lesson from Accidentology ». SAE Paper No.973333, Proceedings of Stapp Car Crash Conference, Orlando, USA, 1997.

2- J.Y Forêt-Bruno et all.: « Correlation Between Thoracic Lesions and Force Values Measured at Shoulder of 92 Belted Occupants Involved in Real Accidents ». SAE Paper No.780892, Proceedings of Stapp Car Crash Conference, USA, 1978.

3- J.Y Forêt-Bruno, F. Brun-Cassan, C. Brigout, C. Tarrière : « Thoracic Deflection of Hybrid III: Dummy Responses for Simulation of Real Accidents » . In proceedings of the 12th International Technical Conference on Experimental Safety Vehicles. Goteborg, Sweden, May 1989. -

4- K. Kompass: « Opportunities and Limits of an Air bag Optimization Based on the Passive Requirements of Standard 208 ». Paper No. 94-S4-O-08, 14th ESV Conference. Munich , Germany.

5- D. Kallieris, A. Rizzeti, R. Mattern, R. Morgan, R. Eppinger and L. Keenan : « On the Synergism of the Driver Air bag and the 3-point Belt in Frontal Collisions ».SAE Paper No.952700, Proceedings of Stapp Car Crash Conference, USA, 1995.

6- H.J. Mertz, J.E. Williamson and D.A. Lugt : « The Effect of Limiting Shoulder Belt Load with Air Bag Restraint ». SAE Paper No.9508861 International Congress and Exposition. Detroit, USA, 1995.

7- ISO/TC22/SC10/WG3 : « NHTSA Communication on Air Bag Related Accidents ». Meeting in Delft, The Nederlands, May, 1997.

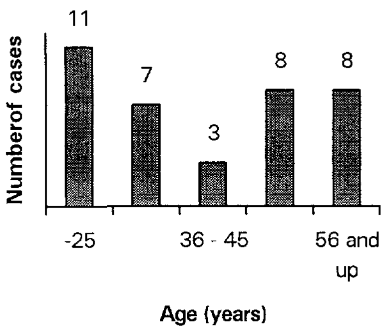
8- ISO/DTR 10982 - Road Vehicles - Test Procedures for Evaluating Out of Position Vehicle Occupant Interactions with deploying Air Bags. November, 1995.

9- Auto Motor und Sport - May 1997 Report - Germany

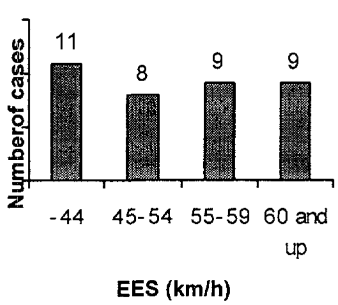
10- « Uniform Provisions Concerning the Approval of Vehicles with Regard to the Protection of the Occupants in the Event of frontal Collision » Official Journal of European Communities, Brussels, July 1996.

11- H.J.Mertz : « Anthropomorphic Test Devices « Accidental Injury - Biomechanics and Prevention, A.M. Nahum and J.M. Melvin, eds, Springer - Verlag 1 New York, 1993.

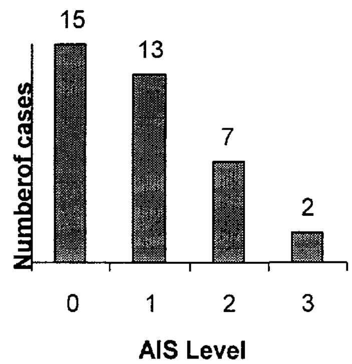
12- X Trosseille, et all : « Evaluation of Secondary Risk with a New Programmed Restraining System ». Paper No.98-S5-W-24. Written paper, 16th International Technical Conference on the Enhanced Safety of Vehicles (ESV), Windsor, Canada, June 1998.



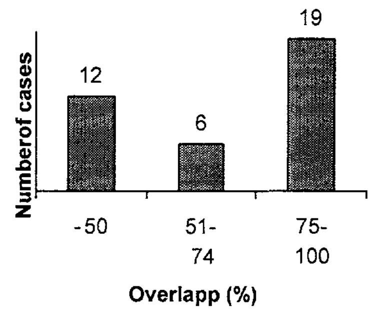
a) : Age distribution



b). Collisions' severity



c): Maximum thoracic AIS



d): Range of overlap

Figure A1 : Summary of data from accident investigations with frontal collisions involving the PRS.

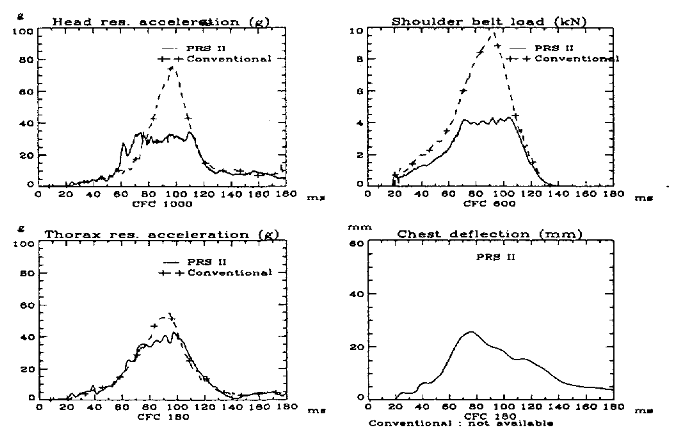


Figure A2 : Comparison of PRS II responses with those of a conventional belt + air bag system. Driver data from a 56 km/h offset rigid barrier test.